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(54) Imaging apparatus and method

(57) The origin of a cone or fan beam of B, γ, or x radiation is moved in a continuous path such as a circle or is stepped among a two-dimensional grid of preselected points. The cone beam of radiation passes through an imaging plane **(44)** in a patient **(14)** and is detected by a detector array **(16)**. A data collection circuit samples the detector array to generate radiation intensity sub-images. A circuit monitors the shifting of the focal spot and controls an image shifting circuit to shift physical coordinates of the sampled sub-image analogously. A sub-imaging combining circuit interleaves or otherwise combines spatially shifted sub-images. In one embodiment, the combined sub-images forms a higher resolution composite image representation. In another embodiment, a plurality of combined, spatially shifted sub-images are collected at angularly offset orientations around the subject and are reconstructed into a higher resolution composite image representation.

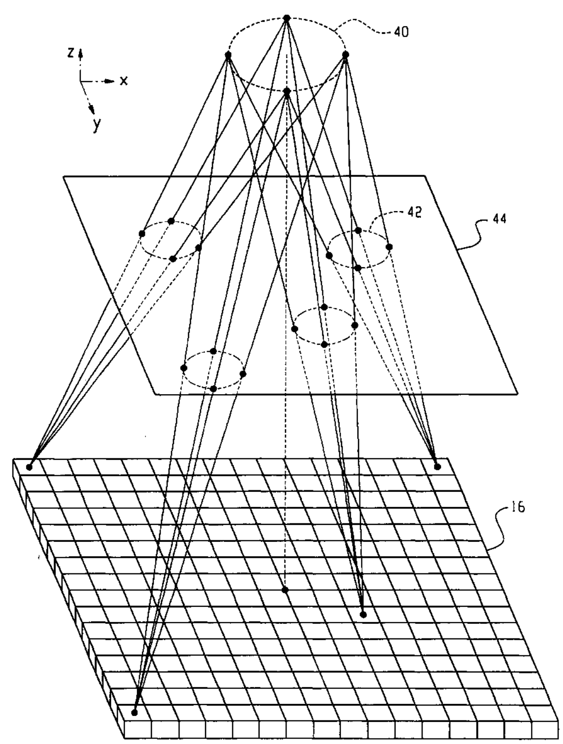

Fig. 2

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Description

[0001] The present invention relates to the field of diagnostic imaging. It finds particular application in conjunction with digital x-ray imaging and will be described with particular reference thereto. However, it is to be appreciated that the present invention also has application in conjunction with computed tomography (CT) scanning and nuclear cameras and is not limited to the aforementioned application.

[0002] The most prominent difference between digital x-ray scanning and classical plane film x-ray is the x-ray detection system. An array of digital detectors replaces the sheet of photosensitive film. Each individual detector within the array detects the intensity of the radiation incident upon its face during the scan and converts that information into an electrical signal. The combined signals are processed and ordered by a computer and converted into a visible display.

[0003] Each individual detector reports only one intensity value, the average intensity along a path with about the same cross-section as the individual detector. However, the data is typically treated as if intensity variations are due solely to the x-ray from the source to the center of the detector. In this manner, the detectors can be thought of as individual pixels of a larger image. The smaller the pixels are, the finer the resolution and the more precise the resulting image. Conversely, if the individual detectors are too small, only a small amount of radiation strikes each detector during a sampling interval. Low amounts of received radiation are sensitive to statistical fluctuation and sampling errors.

[0004] In a more complex solution, the paths of the central rays are shifted half a pixel and the detectors sampled again. In this manner, the effective number of pixels is doubled. However, mechanically shifting the detector array rapidly and precisely is difficult. Often, vibration occurs providing uncertainty and inaccuracy in the true path of the central rays, which blurs the resultant image.

[0005] U.S. Patent No. 4,637,040 (Sohval and Freundlich) alternates between two x-ray sources. The patent also suggests physically shifting a single x-ray source during rotation of a CT scanner, such as with a pair of x-ray tubes or a single tube with two distinct focal spots.

[0006] In accordance with one aspect of the present invention, an apparatus provides an image of a subject located in an imaging region with data sampled from the subject using penetrating radiation. A source of penetrating radiation transmits radiation through the subject. A detector array detects the radiation from the source after passage of the radiation through the subject. A displacing means displaces the source of radiation in two dimensions causing the radiation beam to traverse a plurality of paths through the subject and to be detected by the detector array to provide the sampled data. A processing means processes the sampled data detected with the radiation source at a plurality of displacements to provide increased spatial resolution in the diagnostic images.

[0007] In accordance with another aspect of the present invention, a radiation source projects radiation through an imaging region. A detector array disposed across the imaging region from the radiation source receives radiation which has traversed the imaging region and converts it into intensity signals. A data collection means collects sets of intensity signals from the detector array. A driving means moves the radiation source relative to the detector array. A data shifting means connected with the driving means shifts coordinates of the sets of intensity signals from the data collection means in accordance with movement of the radiation source. A shifted data combining means combines shifted data signals from the data collection means generated at a plurality of shifts of the radiation source to generate improved resolution images.

[0008] In accordance with another aspect of the present invention, a method of improving the spatial resolution of diagnostic images constructed by a digital x-ray scanner is provided. The scanner has a source of penetrating radiation for transmitting radiation through a subject in an imaging region and a detector array to detect the radiation transmitted through the subject along a plurality of rays. The sample density is increased by interleaving radiation rays. Radiation rays are emitted from the source as the position of the source is varied relative to the detector in two dimensions. The detected radiation is processed at various source positions to provide increased spatial resolution of an output image.

[0009] In accordance with another aspect of the present invention, a method of diagnostic imaging is provided. Electrons are accelerated towards a focal spot on an anode to generate a beam of radiation. The radiation beam passes through an imaging region and is converted into a two-dimensional array of intensity values. The intensity values are sampled as the focal spot moves around the anode to a plurality of locations. The sampled two-dimensional arrays of intensity values are shifted in accordance with the shifting of the focal spot and interleaved into an image representation.

[0010] One advantage of the present invention is that it increases the spatial resolution of a digital x-ray scanning system.

[0011] Another advantage of the present invention is that it can avoid the requirement for moving parts to be added to the system.

[0012] Another advantage of the present invention is that it increases digital sampling density.

[0013] Yet another advantage of the present invention is that it is cost-effective.

[0014] Ways of carrying out the invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which:

FIGURE 1 is a diagrammatic illustration of a digital

x-ray scanner in accordance with the present invention;

FIGURE 2 is an x-ray trajectory plot that illustrates the path of a plurality of x-rays from an oscillating source, through a plane of imaging, to an array of detectors in accordance with the present invention;

FIGURE 3 is a diagrammatic illustration of the reconstruction process in accordance with the present invention; and

FIGURE 4 is a cross-sectional view of an x-ray emitter looking in along the z-axis in accordance with the present invention.

[0015] With reference to FIGURE 1, a digital x-ray system is provided. A radiation source **10** emits a cone or fan of x-rays which pass through an imaging region **12** and through a subject **14** to a two-dimensional radiation detector array **16.** Alternatively, the radiation source could be arranged to emit β particles, γ rays or other penetrating radiation. In nuclear medicine, the radiation source is a radioisotope.

[0016] In a CT embodiment, a fan or cone of radiation would be projected onto a one or two-dimensional array. The x-ray source would be mounted for rotation about the subject. The detectors would either rotate with the x-ray source or extend in a circumferential arc around the subject.

[0017] The x-ray or other radiation is differentially attenuated by the tissue along each ray between the source and individual detectors. Optionally, a collimator **18** collimates the radiation beam into individual beams focused on the central portion of each detector. Physical filters for beam hardness correction are optionally disposed between the source and the subject **14.** Each individual detector in the detector array **16** senses the intensity of the x-rays incident upon its face. This intensity value is turned into a gray scale value which is read by a data collection circuit **20.** The gray scale values range from white to black, black corresponding to all of the x-rays reaching the detector, and white corresponding to none of the x-rays reaching the detector. Typically, the detection devices are capable of resolving approximately 2^{32} gray scale values, i.e., resolve the gray scale with 32 bit accuracy.

[0018] In the simplest case, the radiation source **10** emits x-rays from a stationary point or focal spot, which provides the detector array **16** with only one view of the subject **14.** Subsequently, each individual detector reports one intensity value to a data collection circuit **20.** The single set of projection data from the data collection circuit **20** is the electronic image representation. In the CT embodiment, each single set of projection data is one of the views for collective reconstruction into an image.

[0019] In accordance with the present invention, the x-ray source **10** has a mechanism to vary the position of the focal spot or other source of the x-rays in two dimensions, for the purpose of providing the detector array **16** with multiple different views of the subject **14.** This concept is illustrated in FIGURE 2. With reference to FIGURE 2, the source moves about a source path **40,** a circle in the illustrated embodiment.

[0020] As the source moves along its path, the ray seen by any individual one of the detectors traverses a corresponding path **42** through an imaging plane **44.** In the illustrated embodiment, the source is positioned at each of four locations along the source path **40.** Of course, the source can be positioned at a larger or smaller number of positions, or can move continuously around the path **40.**

[0021] With reference again to FIGURE 1, a user input device **50** enables the user to instruct the system regarding a desired resolution improvement. A resolution control circuit **52** issues control signals to an x-ray source driver circuit **54** which causes the x-ray source to move continuously or intermittently around the source path **40.** The resolution control circuit also sends a sampling signal to the data collection circuit **20** to control sampling of the detector array in coordination with movement of the x-ray source. After the data is collected at one of the positions of the x-ray source, the collected data is moved to a sub-image memory **55.** A source shift monitoring circuit **56** monitors movement of the x-ray source and sends a corresponding signal to an image shifting circuit **58.** More specifically, as seen in FIGURE 2, the data sensed by any given pixel of the array shifts along the path **42** on the image plane. The image shift circuit **58** creates a corresponding shift in the data. An image combining or reconstruction device **60** combines the shifted data. In the digital x-ray embodiment, the combined, shifted data is loaded into an image memory **62.** In the CT embodiment, each of the combined, shifted data sets is one view. The one or two-dimensional views generated at different angular orientations around the subject are reconstructed by a reconstruction processor **64** using a convolution-backprojection or other conventional reconstruction algorithm into a two or three-dimensional image representation that is loaded in the image memory **62.** In nuclear cameras, volume images are generated analogously from the γ radiation emitted by radioisotopes. A video processor **66** converts images from the image memory into appropriate format for display on a human-readable monitor **68,** such as a video monitor, LCD display, active matrix display, or the like.

[0022] A four sampling point embodiment of this concept is illustrated in FIGURE 3. Although circular paths are illustrated, it is to be appreciated that other trajectories are also contemplated. In this example, there are four detectors in the array **16** and four sub-images each containing four pixels are generated. Pixel values **101, 105, 109,** and **113** are sampled by the upper left detector. Pixel values **104, 108, 112,** and **116** are sampled by

the lower right detector, and so forth. As the x-ray source rotates clockwise around the path **40,** data is collected at four points. The size of the source path **40** is selected relative to the geometry of the image plane and the detector array such that the second sampling position **102, 106, 110, 114** is shifted by a half pixel to the right. In the third position around the source circle, each ray passes through the image plane a half pixel to the right and a half pixel down and is sampled as sample values **104, 108, 112, 116.** In the fourth position of the source around the path **40,** the ray passes through the image plane a half pixel below the first sampling position. The shifting circuit **58** shifts each of the four sub-images by a half pixel in the appropriate lateral and vertical direction and the combining processor **60** loads the shifted images into the image memory **62.** Of course, this four element array is for simplicity of illustration. In practice, arrays are more commonly 256x256, 512x512, 1024x1024, or the like.

[0023] With reference to FIGURE 4, the x-ray source is an x-ray tube, in the preferred embodiment. The x-ray tube **10** includes a cathode **70** having a filament and a rotating anode **72.** Optionally, the anode can be stationary. Beams of electrons emanating from the filament are accelerated toward the anode and deflected around or to selected points along the source path **40** by the four deflection plates **74, 76, 78, 80,(80** behind **78).** Two of the deflection plates **74, 76** control the movement of the beam in the y-direction, and two of the plates **78, 80** control the movement of the beam in the x-direction.

[0024] In the preferred embodiment, the voltage applied to the deflection plates varies sinusoidally. Plates **78** and **80** are 90° out of phase with respect to plates **74** and **76.** As a result, the electron beam traces a circle that processes about the source path **40** continuously. Alternately, the voltages can be applied to the deflection plates in steps to step the electron beam around the path **40** in steps.

[0025] Alternate deflection techniques are also contemplated. For example, magnetic coils can be utilized to deflect the electron beam. As yet another alternative, the x-ray tube can be mechanically moved. As yet another example, the cathode or the anode can be moved within the x-ray tube. As yet another option, the x-ray tube can have multiple cathodes, each focused on an incrementally shifted portion of the anode so that the focal spot is shifted by switching from cathode to cathode. As yet another option, a single cathode can be provided with multiple, offset filaments.

[0026] It is to be appreciated that the focal spot can be moved in other than circular trajectories. For example, the detector array can be a one-dimensional array of detectors. The focal spot is then swept back and forth either in steps or continuously in a direction parallel to the one-dimensional array. After sampling the detector array with the x-ray spot in each of a plurality of positions, e.g., four, the subject is indexed relative to the x-ray source and detector array in a direction perpendicular to the detector array. In the new position, the focal spot is again swept and another series of one-dimensional images collected. The sub-images of each line are interleaved and the lines are stacked to form a two-dimensional image. Alternately, the x-ray source and detector can be rotated around the subject and the interleaved data lines reconstructed to form a slice image representation. This same principal can be extended to volumetric images using either two-dimensional arrays or physically stepped one-dimensional arrays.

[0027] With two-dimensional detector arrays, various patterns for moving the focal spot are contemplated. For example, the focal spot can be stepped among the four corners of the square. For a finer resolution, the focal spot can be stepped among an mxn array of linear positions arranged in a grid, where m,n are plural integers. As another option, a large number of shifted images are generated and stacked. The pixels of the resultant image are projected through the stacked images and weightedly averaged. This technique is particularly advantageous when the focal spot is not sampled at a periodically changing position and where the resolution of the final image does not match the resolution of the interleaved shifted images.

Claims

1. Apparatus for providing an image of a subject **(14)** located in an imaging region **(12)** with data sampled from the subject **(14)** using penetrating radiation, the apparatus comprising: (a) a source **(10)** of penetrating radiation for transmitting the radiation through the subject **(14);** (b) a detector array **(16)** for detecting the radiation from the source **(10)** after passage of the radiation through the subject **(14);** (c) means **(54)** for displacing the source **(10)** of radiation in two dimensions to cause the radiation beam from the source **(10)** to traverse a plurality of paths through the subject **(14)** and to be detected by the detector array **(16)** to provide sampled data; (d) processing means **(64)** for processing the sampled data detected with the radiation source at a plurality of displacements to provide increased spatial resolution in the diagnostic images.

2. Apparatus as claimed in claim 1, wherein the detector array **(16)** includes: a two-dimensional plurality of individual detectors disposed substantially uniformly along a fixed support adjacent the imaging region **(12)** across from the source **(10)** of the radiation.

3. Apparatus as claimed in claim 1 or claim 2, wherein the radiation source **(10)** includes: a target anode **(72)** for emitting radiation in response to a beam of electrons colliding therewith and deflecting means **(74, 76, 78, 80)** for deflecting the electron beam in

two dimensions between a plurality of focal spots on the anode **(72).**

4. Apparatus as claimed in claim 3, wherein the deflecting means **(74, 76, 78, 80)** includes: at least three electrostatic or magnetic elements for deflecting the beam in two dimensions.

5. Apparatus as claimed in claim 3 or claim 4, wherein the deflecting means **(74, 76, 78, 80)** is arranged to cause the focal spot of the beam of electrons on the anode **(72)** to move sinusoidally in two dimensions.

6. Apparatus as claimed in any one of claims 1 to 5, wherein the radiation source **(10)** emits a cone beam of radiation, and further including: a post-patient collimator means **(18)** for reducing the height and width of the radiation beam which is detected by the detector array **(16),** and means for further increasing the sampling density.

7. Apparatus as claimed in claim 6, wherein the means for further increasing the sampling density includes: a plurality of point sources of radiation within the source located on a source circle **(40)** projected on the anode **(72).**

8. Imaging apparatus comprising: a radiation source **(10)** for projecting radiation through an imaging region **(12);** a detector array **(16)** disposed across the imaging region **(12)** from the radiation source **(10)** for receiving radiation which has traversed the imaging region **(12)** and converting received radiation into intensity signals; data collection means **(20)** for collecting sets of the intensity signals from the detector array **(16);** driving means **(54)** for moving the radiation source **(10)** relative to the detector array **(16);** data shifting means **(58)** connected with the driving means **(54)** for shifting coordinates of the sets of intensity signals from the data collection means **(20)** in accordance with movement of the radiation source **(10);** shifted data combining means **(60)** for combining shifted signal sets from the data collection means **(20)** generated at a plurality of shifts of the radiation source **(10)** to generate improved resolution images.

9. Imaging apparatus as claimed in claim 8, further including: a reconstruction processor **(64)** for reconstructing a plurality of the combined signal sets collected at a plurality of angular increments around the imaging region **(12)** into an image representation; an image memory **(62)** for receiving and storing the image representation.

10. Imaging apparatus as claimed in claim 8 or claim 9, wherein the radiation source **(10)** includes: an x-ray tube and the driving means **(54)** is arranged to move a focal spot of the x-ray tube.

11. Imaging apparatus as claimed in claim 10, wherein the radiation source **(10)** includes an x-ray tube having a cathode **(70)** for generating electrons which are accelerated toward an anode **(72)** and a beam deflecting means **(74, 76, 78, 80)** for deflecting the electron beam such that in use the radiation beam moves in a pattern on the anode **(72)** under the control of the driving means **(54).**

12. Imaging apparatus as claimed in claim 11, wherein the driving means **(54)** is arranged to move the focal spot in a continuous pattern.

13. Imaging apparatus as claimed in claim 11 or claim 12, wherein the driving means **(54)** is arranged to step the focal spot among a plurality of preselected locations on the anode **(72).**

14. A method of improving the spatial resolution of images constructed by a digital scanner, having a source **(10)** of penetrating radiation for transmission through a subject **(14)** in an imaging region **(12),** a detector array **(16)** to detect the radiation transmitted through the subject **(14)** along a plurality of rays, the method comprising: (a) increasing the sampling density by interleaving radiation rays, including: emitting radiation rays from the source **(10);** and varying a position of the source **(10)** relative to the detector two dimensions; (b) processing the detected radiation at the varied source positions to provide increased spatial resolution of an output image.

15. A method as claimed in claim 14, wherein the processing step includes: (i) reading a set of data in each source position; (ii) spatially shifting the data sets; (iii) combining the spatially shifted data sets.

16. A method as claimed in claim 15, further including: repeating steps (i) (ii), and (iii) while moving the radiation source **(10)** and detector array **(16)** around the subject **(14);** reconstructing the combined spatially shifted data sets, generated as the source **(10)** and detector array **(16)** are moved around the subject **(14),** into the output.

17. A method of diagnostic imaging comprising: accelerating electrons toward a focal spot on an anode **(72)** to generate a beam of radiation; passing the radiation beam through an imaging region **(12);** converting radiation passing through the imaging region into a two-dimensional array of intensity values; sampling the intensity values; moving the focal spot around the anode **(72)** to a plurality of locations; shifting the sampled two-dimensional arrays of intensity values in accordance with shifting of the

focal spot; interleaving the shifted two-dimensional arrays of intensity values into an image representation.

18. A method as claimed in claim 17, wherein the focal spot is moved in a circular path **(40)** on the anode **(72).**

19. A method as claimed in claim 17, wherein the focal spot is stepped among a two-dimensional array of locations on the anode **(72).**

20. A method as claimed in any one of claims 17 to 19, wherein the focal spot moves continuously on the anode **(72)** and wherein each sampled array of intensity values is shifted in accordance with a median position of the focal spot during a sampling interval.

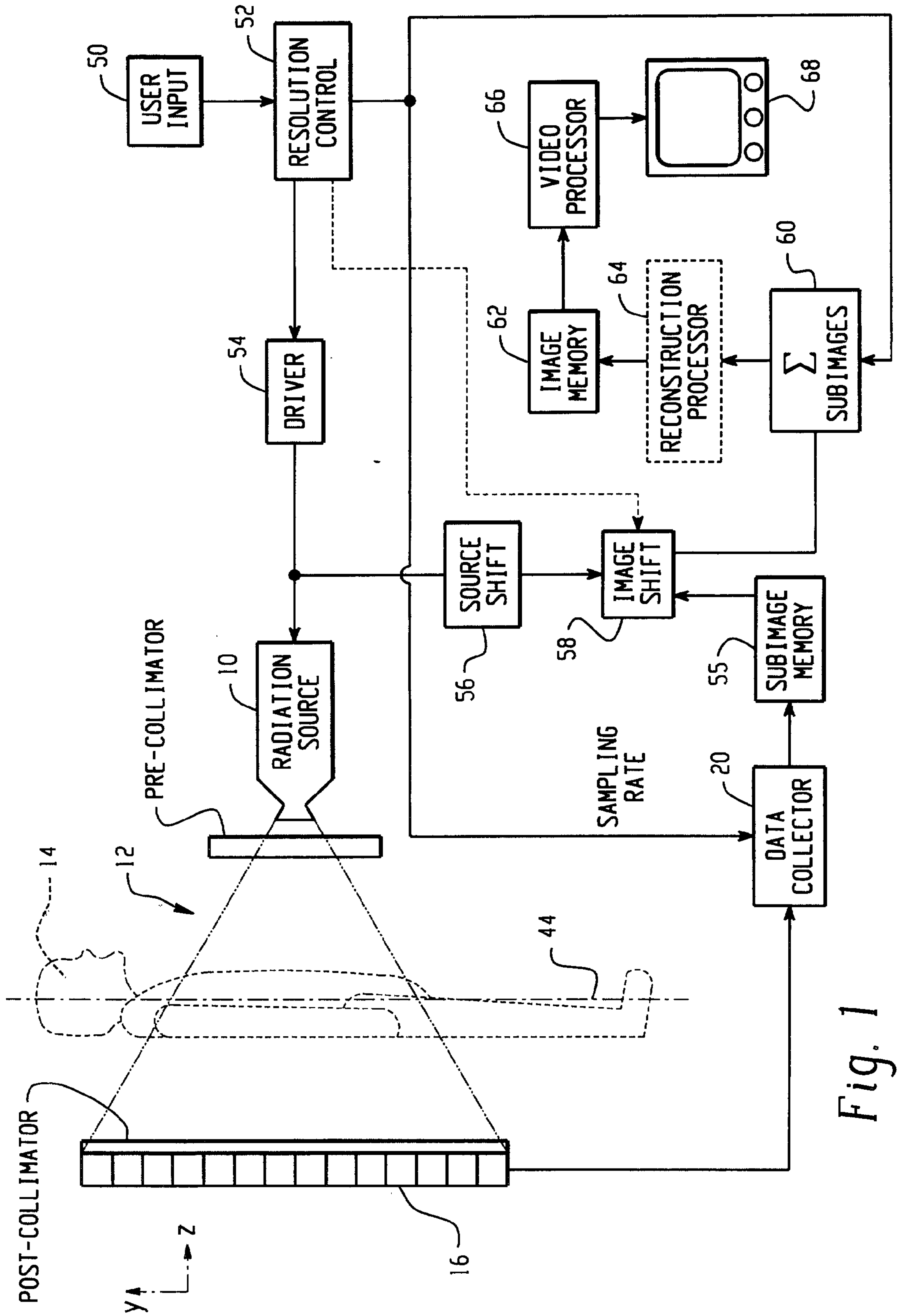
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Fig. 1

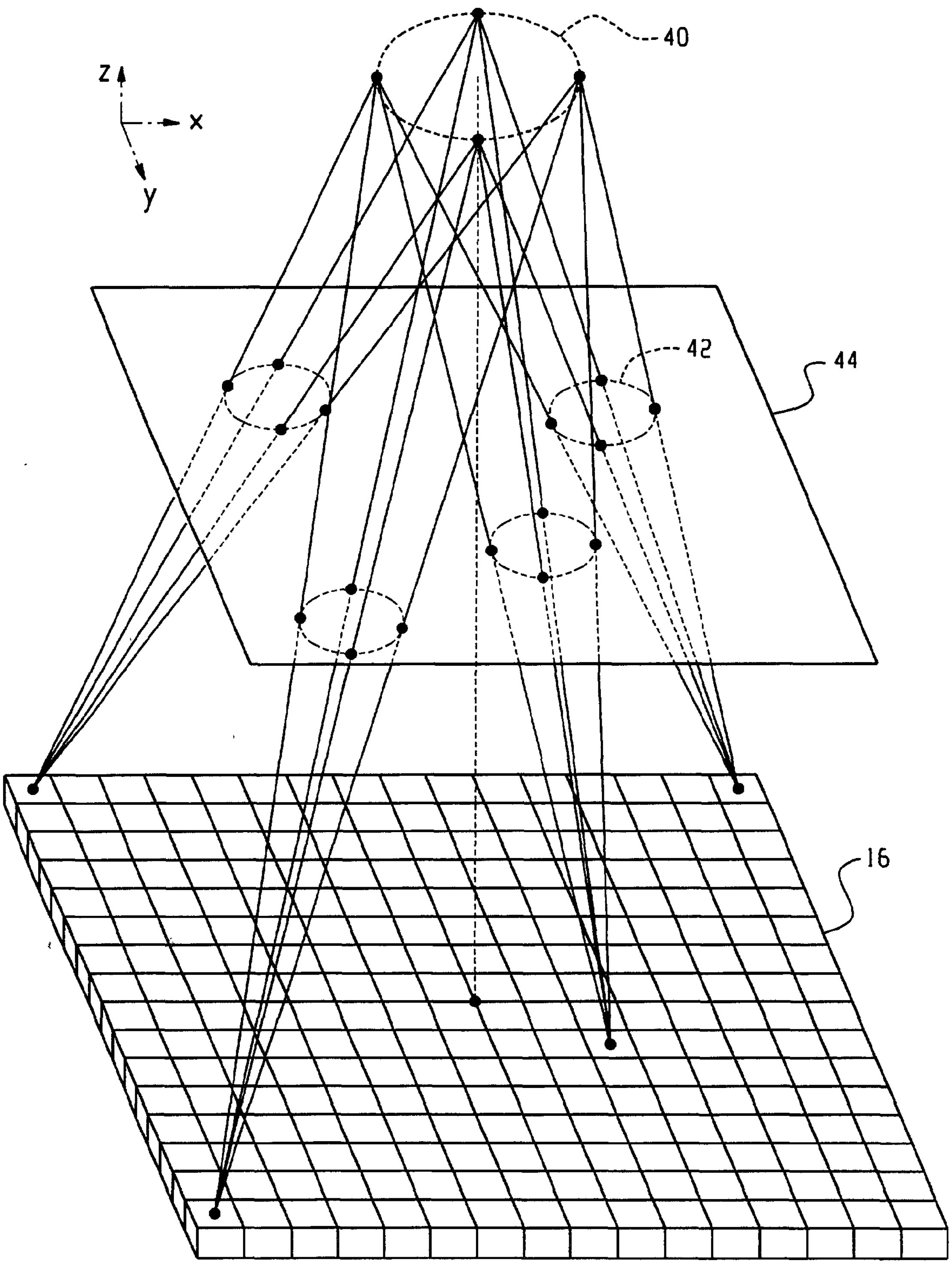

Fig. 2

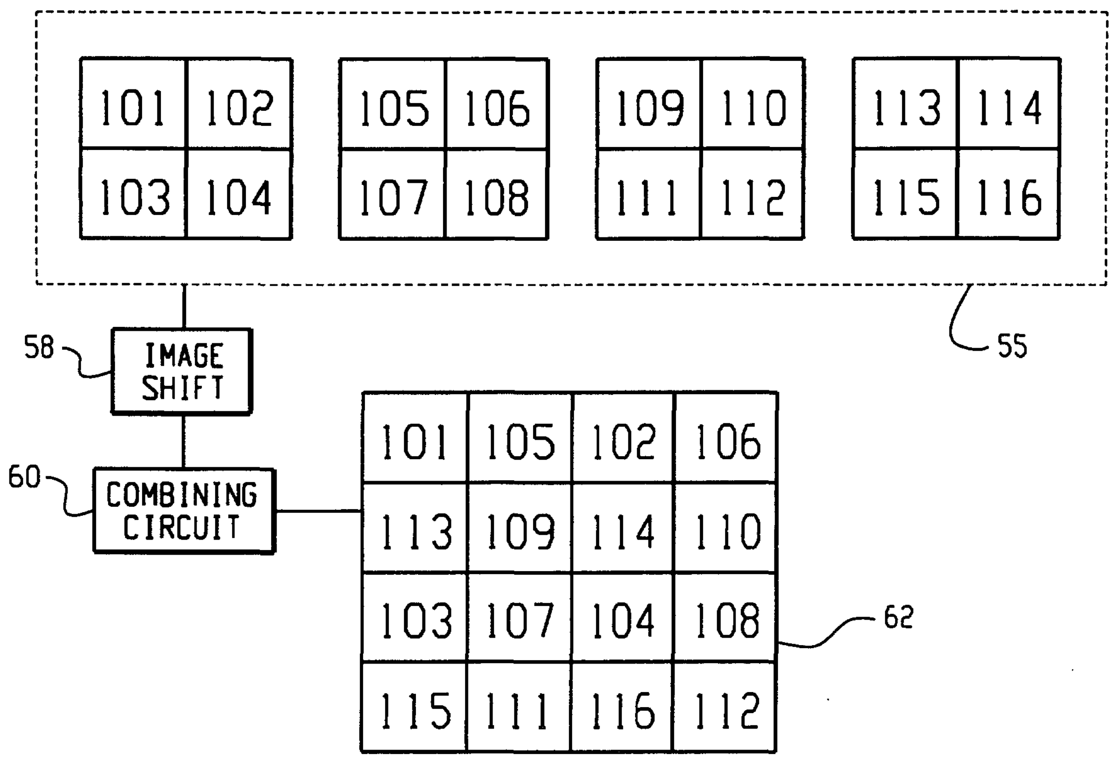
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Fig. 3

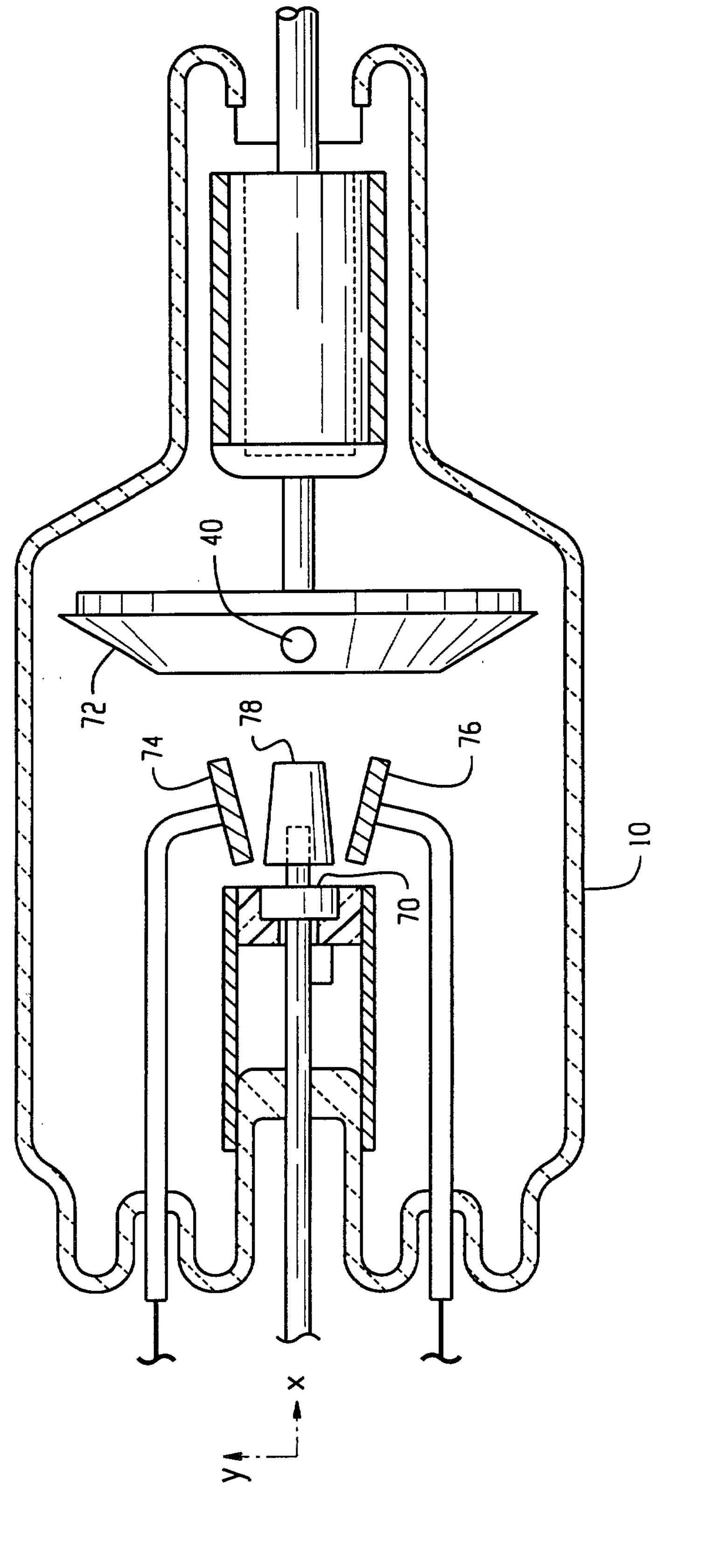

Fig. 4

European Patent Office

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Application Number
EP 01 30 9937

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 March 2002	Oestreich, S

CATEGORY OF CITED DOCUMENTS

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